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Original Contribution

The Relation between Neighborhood Built Environment and Walking Activity among Older Adults

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The association of neighborhood built environment with walking activity has received growing attention, although most studies have relied upon subjective measures of the built environment and few have examined the relation between built environment and walking among older adults. This 2001 study examined the relation between objectively measured characteristics of the local neighborhood and walking activity among a sample of 546 community-dwelling older adults in Portland, Oregon. A geographic information system was used to derive measures of the built environment within a quarter-mile (0.4 km) and half-mile (0.8 km) radius around each participant's residence. Multilevel regression analysis was used to examine the association of built environment with walking behavior. No association between built environment and the likelihood of walking or not walking was observed in this cohort of older adults. However, among those participants who reported some degree of walking activity, average time spent walking per week was significantly associated with amount of automobile traffic and number of commercial establishments in their local neighborhood. These findings suggest that built environment may not play a significant role in whether older adults walk, but, among those who do walk, it is associated with increased levels of activity.

aged; environment design; geographic information systems; health behavior; regression analysis; residence characteristics; urban health; walking

Abbreviation: SHAPE, Senior Health and Physical Exercise.

Physical activity is an important determinant of health among older adults. Regular physical activity reduces the risk of chronic disease and improves functional ability, mood, and quality of life (1–3). Walking is the most common form of physical activity in the United States, and promoting walking is an important component of efforts to improve overall physical activity levels among older adults (4–6).

A growing body of evidence suggests that neighborhood built environment may significantly influence whether and how often individuals engage in walking. Recent studies have found significant associations between walking behavior and, for example, proximity of parks, public spaces, or commercial establishments (7–9); sidewalk condition (10); population density (11); land-use mix (12, 13); and neighborhood aesthetics (14, 15). However, the majority of these studies have relied upon subjective measures of the built environment in self-defined neighborhoods or in neighborhoods defined by census boundaries (16). Furthermore, few studies have explored the relation between neighborhood built environment and walking among older adults (17).

This study addresses the current gap in the literature and extends the study by Li et al. (18) reporting significant

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TABLE 1. Characteristics of municipally defined study neighborhoods (n = 56), Senior Health and Physical Exercise trial, Portland, Oregon, 2001

	Mean (SD*)	Range
Area (acres†)	883.4 (1,022.9)	115.0–7,055.0
Population	6,926.9 (3,963.1)	241.0–19,615.0
Density (persons per acre)	10.5 (5.0)	1.40–34.22
Ethnicity (proportion of White residents)	0.8 (0.2)	0.3–1.0
Poverty (proportion of households with income <$15,000)	0.2 (0.1)	0.1–0.5
Crime rate (per person against persons/property)	0.4 (0.2)	0.1–1.9
Perceived neighborhood problems (range of possible scores: 7–35)	14.4 (2.8)	8.4–20.7
Perceived safety for neighborhood walking (range of possible scores: 1–5)	4.5 (0.3)	3.4–4.9

* SD, standard deviation.
† One acre = 4,047 m^2.

associations between neighborhood characteristics and overall physical activity among older adults in Portland, Oregon. In that study, built environment characteristics were measured primarily at the municipally defined neighborhood level, and only two built environment characteristics—number of intersections and total area of green space—were measured objectively at the local neighborhood level. The current study expands upon those initial findings by examining the relation between participants' estimated duration of weekly walking time and additional objective measures of the local built environment measured at both the quarter-mile (0.4 km) and half-mile (0.8 km) radii around each subject's residence.

MATERIALS AND METHODS

Study design and data collection

We conducted a cross-sectional observational study of individuals enrolled in the Senior Health and Physical Exercise (SHAPE) trial, a cluster-randomized, controlled trial of a neighborhood-based walking promotion intervention for seniors (19). Fifty-six neighborhoods were selected from a total of 93 neighborhoods in Portland. Each neighborhood has municipally defined boundaries, a neighborhood association, and a publicly available sociodemographic profile. Low-socioeconomic-status and high-minority neighborhoods in the city were oversampled. Neighborhoods were randomly assigned to either a leader-guided neighborhood walking condition (n = 28) or an education-only control condition (n = 28). Characteristics of the study neighborhoods are presented in table 1. Potential participants were recruited from the 56 neighborhoods by using residential addresses generated by a computer-assisted telephone interview system, followed by direct mail, and personal contact methods. Inclusion criteria for the SHAPE trial enrollees were 1) aged 65 years or older, 2) cognitively intact, 3) no participation in a formal exercise program during the previous month, and 4) able to walk unassisted. The data used to calculate the outcome measures and individual-level covariates presented in this paper were collected from participants at baseline. The built environment measures and neighborhood-level covariates derived from a geographic information system were constructed and measured following completion of the study.

Walking behavior. The Yale Physical Activity Scale, an interviewer-administered questionnaire with demonstrated validity among older adults, was used to calculate each participant's weekly walking time (20–22). Total weekly walking time was calculated by summing the brisk walking and leisure walking items from the Yale Physical Activity Scale activities checklist. Subanalyses of the relation between the built environment measures and participants' brisk and leisure walking times were also performed. After observing that a small proportion of participants reported implausibly high walking times, we trimmed the top 5 percent of reported walking times such that the highest number of minutes walked per week was 403. Doing so resulted in a loss of 28 participants.

Built environment. Built environment characteristics were assessed for the local neighborhood environment of each participant (table 2). These characteristics were assessed with the assistance of Metro, the regional planning agency for the Portland metropolitan area. ArcGIS 9.1 software (ESRI, Redlands, California) was used to geocode participants by baseline residential address, which was linked to existing maps in the Regional Land Information System database maintained by Metro. Eight participants could not be geocoded and were subsequently excluded from analysis. Data from the Regional Land Information System were used to calculate measures of automobile traffic volume on local streets, sidewalk coverage, intersection frequency, and public transportation access within quarter-mile and half-mile radii around each residential address. The numbers and types of retail establishments surrounding each participant's residence were obtained by merging publicly available directory information with the geographic information system layers. In addition to total retail establishments, we calculated the frequency of establishments identified in previous research as being likely walking destinations (23). These "select establishments" consisted of the following categories: convenience, deli, or grocery stores; department, discount, or hardware stores; restaurant, pub, or bar; library; post office; church; and community center. Lastly, the Euclidian distance from each participant's residence to the nearest park/green space was calculated.

Individual-level covariates. The baseline SHAPE interview included items assessing participants' age, gender, race, educational level, household income, self-reported health status, and walking self-efficacy. Age was calculated at the initial interview and was retained as a continuous variable. Race was collapsed into the categories White and non-White, years of education was categorized at the median (0–12 years, ≥13 years), and annual household income was categorized into tertiles (<$15,000, $15,000–$29,999, ≥30,000). Participants were asked to rate their general health on a five-point scale

TABLE 2. Characteristics of the local built environment around participants' homes, Portland, Oregon, 2001

Built environment characteristic	Quarter mile*		Half mile	
	Mean (SD†)	Range	Mean (SD)	Range
Percentage of high-volume streets	5.5 (8.4)	0–45.4	6.9 (7.2)	0–36.9
Percentage of medium-volume streets	8.4 (7.5)	0–36.0	8.3 (5.2)	0–24.2
Percentage of low-volume streets	82.6 (10.8)	44.8–100.0	80.9 (9.0)	53.1–98.4
Percentage of sidewalk coverage	48.4 (26.8)	0–100.0	55.1 (22.4)	1.3–97.7
No. of intersections	55.4 (16.2)	23.0–123.0	218.5 (54.2)	106.0–412.0
No. of bus lines	2.5 (4.1)	0–50.0	4.9 (6.4)	1–51.0
No. of commercial establishments	45.5 (86.0)	1.0–1,403.0	178.1 (267.4)	9.0–3,080.0
No. of select establishments	11.4 (18.9)	0–243.0	42.7 (50.7)	1–525.0
Euclidian distance to the nearest park (feet‡)	8,74.5 (582.0)	3.6–3,156.1		

* One mile = 1.609 km.
† SD, standard deviation.
‡ One foot = 0.3 m.

(poor, fair, good, very good, excellent), which was then collapsed into two categories: poor to fair, and good to excellent. Walking self-efficacy was assessed with two scales adapted from McAuley and Mihalko (24). To measure behavioral self-efficacy, participants were asked whether they were confident that they could walk at least three times per week for 5, 10, 20, 30, 40, 50, and 60 minutes. To assess self-efficacy regarding barriers, they were asked whether they could walk for 30 minutes in the presence of barriers (e.g., poor weather, scheduling conflicts). All items were rated on a five-point scale ranging from 1 (not confident at all) to 5 (completely confident). The average score for each measure was calculated, and the two scores were summed to create a comprehensive measure of walking self-efficacy.

Neighborhood-level covariates. Neighborhood-level measures included poverty, perceived problems, and perceived walking safety. Neighborhood household income data were obtained from the 1996 American Community Survey and were compiled by the Office of Neighborhood Involvement in Portland (25). Poverty was measured as the proportion of households in the municipally defined neighborhood with annual incomes of less than $15,000. Perceived problems were assessed on a seven-item scale adapted from Sallis et al. (26). Participants were asked to rate, on a scale ranging from 1 (strongly disagree) to 5 (strongly agree), whether gangs, graffiti, violent crime, vandalism, burglary, abandoned or boarded-up buildings, and alcohol or drug use were problems in their neighborhood. Individual scores were summed and then aggregated at the neighborhood level, with a higher score indicating more perceived problems. Perceived neighborhood walking safety was assessed with one item from Sallis et al., which asked participants to rate the extent to which they agreed with the following statement: "It is safe to walk or jog alone in my neighborhood during the day." This item was rated on a five-point scale from 1 (strongly disagree) to 5 (strongly agree) and was aggregated to the neighborhood level. A higher score indicated a greater degree of perceived safety for walking.

Statistical analyses

The association between built environment and walking activity was analyzed by constructing multilevel regression models with individuals at level 1 and municipally defined neighborhoods at level 2. This approach was chosen to account for the nested data structure arising from the multistage, cluster-randomized design of the SHAPE study. We elected a two-phase analysis approach because total, brisk, and leisure walking followed mixture distributions. In phase 1, we constructed multilevel linear regression models of the association between each built environment measure and duration of total walking per week among participants who reported engaging in some degree of walking activity—either brisk walking, leisure walking, or both. We also performed subgroup analyses of both brisk walking time and leisure walking time, including only those participants who reported engaging in that type of walking. In phase 2, we constructed multilevel logistic regression models of the relation between each built environment characteristic and the odds of reporting any duration of walking versus reporting no walking. Separate models for each built environment characteristic were built because of the high degree of spatial correlation between several of the built environment variables.

Analysis of walking time began by calculating the intraclass coefficient from the unconditional means model of each walking type to estimate the proportion of total variance in walking time attributable to between-neighborhood differences. Next, we tested random intercept and slope models of each built environment characteristic and walking duration. The estimated slope variance and intercept-slope covariance in each of these models was insignificant, indicating that the effect of the modeled built environment characteristic on walking time did not vary significantly across municipally defined neighborhoods (27). Random intercept models with fixed slopes were constructed for all subsequent analyses.

TABLE 3. Characteristics of study participants, Senior Health and Physical Exercise trial, Portland, Oregon, 2001

	Total walking time = 0 (n = 120)		Total walking time >0 (n = 426)		Total sample (N = 546)	
	No.	%	No.	%	No.	%
Gender						
Male	32	26.7	132	31.0	164	30.0
Female	88	73.3	294	69.0	382	70.0
Race						
White	101	84.2	383	90.5	484	89.1
Other	19	15.8	40	9.5	59	10.9
Annual household income						
<$15,000	58	48.3	146	34.3	204	37.4
$15,000–$29,999	37	30.8	119	27.9	156	28.6
≥$30,000	25	21.4	161	37.8	186	34.1
Education (years)						
0–12	69	57.4	172	40.5	241	44.2
>12	51	42.5	253	59.5	304	55.8
Health status						
Poor to fair	20	16.7	58	13.6	78	14.3
Good to excellent	100	83.3	368	86.4	468	85.7
Age in years (mean (SD*))	76.0 (7.0)		74.1 (6.0)		74.5 (6.3)	
Walking self-efficacy score (mean (SD))	6.7 (2.4)		7.9 (1.7)		7.6 (1.9)	

Minutes of reported walking time	Mean (SD)	Range
Total walking time (n = 426)	130.98 (90.96)	7.00–402.50
Brisk walking time (n = 275)	101.92 (75.82)	2.00–360.00
Leisure walking time (n = 330)	84.16 (67.13)	6.25–375.00

* SD, standard deviation.

The relation of each built environment characteristic to each walking type (total, brisk, and leisure) was examined in sequential multilevel regression models. Model 1 was a simple univariate model of the association between a single built environment variable and walking time. This univariate model was extended in model 2 to include the built environment variable and all individual-level covariates (age, race, gender, household income, educational level, health status, walking self-efficacy). Model 3 contained the built environment variable and all neighborhood-level covariates (poverty, neighborhood problems, walking safety). Finally, in model 4, all covariates were added to the model with the built environment variable. Additionally, to independently examine the relation between sociodemographic variables and walking time, models containing only the individual-level and neighborhood-level covariates were constructed. Multilevel logistic regression analyses assessing the association between built environment and reported walking (any/none) were carried out in a similar fashion. Random intercept models of the association between each built environment variable and the likelihood of walking were fit to the data. Models were fit in sequential order, adjusting for individual-level and neighborhood-level covariates as described in the section above. Multilevel analyses were conducted by using the PROC MIXED and PROC GLIMMIX procedures in SAS v.9 software (SAS Institute, Inc., Cary, North Carolina).

RESULTS

Characteristics of the study population are presented in table 3. A total of 546 participants were included in the analysis, with an average of 10 participants per neighborhood (range: 3–17). Mean age was 74 years, and participants were primarily White (89 percent) and female (70 percent) and reported themselves to be in good-to-excellent health (86 percent). Roughly 22 percent (n = 120) reported no brisk or leisure walking. Participants who reported walking engaged in an average of 130.98 (standard deviation, 90.96) minutes of walking per week, slightly less than the minimum recommendation of 150 minutes per week (30 minutes on at least 5 days). More participants reported walking for leisure (n = 330) than walking briskly (n = 275), although mean walking time was higher for brisk walking than for leisure walking (table 2).

TABLE 4. Association of local built environment characteristics with total walking time, Senior Health and Physical Exercise trial, Portland, Oregon, 2001

Built environment characteristic	Model 1: no additional covariates	Model 2: individual-level covariates added†	Model 3: neighborhood-level covariates added‡	Model 4: all covariates added	
	β (SE§)	β (SE)	β (SE)	β (SE)	Adjusted β¶
Quarter-mile# buffer					
Percentage of high-volume streets	1.10 (0.52)*	1.27 (0.5)*	0.89 (0.53)	1.00 (0.50)*	8.42*
Percentage of medium-volume streets	0.83 (0.62)	0.73 (0.6)	0.72 (0.61)	0.66 (0.59)	4.96
Percentage of low-volume streets	−1.23 (0.41)**	−1.36 (0.4)**	−1.03 (0.42)*	−1.16 (0.40)**	−12.48**
Percentage of sidewalk coverage	0.20 (0.18)	0.16 (0.17)	0.24 (0.18)	0.18 (0.17)	4.82
No. of intersections	0.35 (0.29)	0.36 (0.27)	0.21 (0.30)	0.17 (0.28)	2.75
No. of bus lines	2.28 (1.25)	2.22 (1.21)	1.24 (1.40)	0.89 (1.35)	3.67
No. of commercial establishments	0.23 (0.06)**	0.25 (0.06)**	0.22 (0.07)**	0.23 (0.07)**	19.77**
No. of select establishments	0.64 (0.26)*	0.68 (0.26)*	0.62 (0.27)*	0.60 (0.27)**	11.32**
Half-mile buffer					
Percentage of high-volume streets	1.58 (0.63)*	1.83 (0.61)**	1.31 (0.64)**	1.5 (0.61)**	10.73**
Percentage of medium-volume streets	1.18 (0.9)	1.15 (0.89)	1.01 (0.89)	1.06 (0.87)	5.47
Percentage of low-volume streets	−1.74 (0.49)**	−1.93 (0.48)**	−1.48 (0.52)**	−1.69 (0.5)**	−15.20**
Percentage of sidewalk coverage	0.33 (0.22)	0.32 (0.21)	0.36 (0.21)	0.33 (0.21)	7.39
No. of intersections	0.16 (0.09)	0.20 (0.08)*	0.12 (0.10)	0.14 (0.09)	7.58
No. of bus lines	1.69 (0.72)*	1.86 (0.70)*	1.11 (0.83)	1.14 (0.81)	7.31
No. of commercial establishments	0.07 (0.02)**	0.07 (0.02)**	0.06 (0.02)**	0.06 (0.02)**	16.05**
No. of select establishments	0.33 (0.09)**	0.34 (0.09)**	0.32 (0.10)**	0.31 (0.1)**	15.72**
Euclidian distance to the nearest park	−0.01 (0.01)	−0.01 (0.01)*	−0.01 (0.01)	−0.01 (0.01)	−5.82

* $p < 0.05$; ** $p < 0.001$.
† Gender, race, age, education, income, health status, walking self-efficacy.
‡ Poverty, neighborhood problems, safety.
§ SE, standard error.
¶ The expected change in minutes of walking time associated with an increase of one standard deviation in the built environment characteristic.
# One mile = 1.609 km.

Built environment and walking activity

We observed that 3.6 percent (intraclass coefficient = 0.036) of the variance in total walking time was attributable to differences in municipally defined neighborhood residence. Among those participants who reported some degree of walking activity, we found significant associations between walking time and several characteristics of the local built environment after adjusting for individual-level and neighborhood-level covariates (table 4). Within a quarter-mile radius around participants' homes, a higher number of commercial establishments ($\beta = 0.23$, $p < 0.001$), select establishments ($\beta = 0.60$, $p = 0.024$), and a greater percentage of high-volume streets ($\beta = 1.00$, $p = 0.048$) were all significantly associated with increased total walking time. Conversely, a higher percentage of low-volume streets ($\beta = -1.16$, $p = 0.004$) was associated with fewer minutes walked per week. At the half-mile buffer, similar associations were observed between total walking time and number of commercial establishments ($\beta = 0.06$, $p = 0.002$), select establishments ($\beta = 0.31$, $p = 0.002$), and percentage of high-volume ($\beta = 1.50$, $p = 0.015$) and low-volume ($\beta = -1.69$, $p < 0.001$) streets. In our logistic regression models comparing those who reported walking with those who reported no walking, there were no significant associations between the likelihood of engaging in walking behavior and any built-environment variables (data not shown).

In subanalyses of brisk and leisure walking, increased brisk walking time was associated with a higher percentage of high-volume streets within a quarter mile around participants' homes ($\beta = 1.11$, $p = 0.028$), and decreased brisk walking time was associated with a higher percentage of lower volume streets ($\beta = -0.85$, $p = 0.042$) at the quarter mile. A higher number of both total ($\beta = 0.04$, $p = 0.016$) and select ($\beta = 0.20$, $p = 0.033$) commercial establishments within a half-mile radius was associated with increased brisk walking time. Lastly, a greater distance from the participants' homes to the nearest park was associated with decreased brisk walking time ($\beta = -0.02$, $p = 0.032$). We found no significant associations between leisure walking time and any built environment characteristics at either the quarter-mile or half-mile buffer (data not shown).

Covariates and walking activity

Several individual-level and neighborhood-level covariates were significantly associated with walking time. At the individual level, higher walking self-efficacy scores were associated with increased total ($\beta = 20.01$, $p < 0.001$), brisk ($\beta = 17.53$, $p < 0.001$), and leisure ($\beta = 7.72$, $p = 0.002$) walking time. We observed significantly increased total ($\beta = 34.23$, $p = 0.028$) and brisk ($\beta = 32.39$, $p = 0.046$) walking time among Whites. Increased age was associated with increased brisk walking time ($\beta = 1.61$, $p = 0.032$). At the neighborhood level, a higher percentage of households with an income of less than \$15,000/year was positively associated with total walking time ($\beta = 195.18$, $p = 0.005$) and leisure walking time ($\beta = 185.07$, $p = 0.001$). Conversely, an increased number of neighborhood problems was associated with decreased total ($\beta = -4.11$, $p = 0.050$) and leisure ($\beta = -5.15$, $p = 0.003$) walking time.

DISCUSSION

Among participants who reported engaging in some degree of walking activity, we found that the overall number of commercial businesses, the number of likely retail walking destinations, and the percentage of high-volume and low-volume streets in their local neighborhood were associated with the total amount of time these participants spent walking each week. Although these findings were qualitatively similar for the quarter-mile and half-mile radii, the magnitude of the observed associations varied depending on the area at which the built environment characteristic was measured. The relation of commercial establishments to walking time was greatest at the quarter-mile, while the relation of street volume to walking time was most pronounced when measured at the half-mile buffer.

These findings support recent observations of significant associations between physical activity and traffic volume, land-use mix, and proximity of walking destinations (7, 28). This study extends those findings to the walking behavior of older adults, a group largely neglected in this area of research. We did not observe any association between walking time and intersection density, percentage of sidewalk coverage, or proximity to public transportation. In our subgroup analyses, we found that brisk walking time was associated not only with street volume and number of retail establishments but also with distance to the nearest park or green space. There were no significant associations between walking for leisure and local neighborhood environment.

Notably, we found no association between any of the built environment measures and the odds of walking or not walking. This finding suggests that features of the local built environment were not strongly correlated with whether or not participants engaged in walking, and it enabled us to conjecture that modifications to the built environment may have little benefit in promoting walking behavior among sedentary older adults. Nevertheless, the finding that built environment is associated with increased walking time among reported walkers is important, given that nearly half of older adults report occasional walking at levels below those required to meet minimum activity guidelines (5, 29).

Among this population, shifting the average time spent walking toward the levels of physical activity recommended would result in substantial public health benefits. In table 4, we provide adjusted parameter estimates that illustrate the expected change in walking time associated with a standard deviation change in each built environment characteristic. While the changes in walking time associated with individual characteristics are fairly modest, the impact of such changes is best seen within the context of the low levels of activity in this population. For example, a 30-minute increase in walking per week amounts to a nearly 25 percent increase from the mean walking time reported by our sample. Among the participants in this study, this increase would be sufficient to shift nearly 30 percent of those not meeting the Centers for Disease Control and Prevention recommendations for physical activity into compliance with current guidelines.

We found that a greater degree of perceived neighborhood problems was associated with less time spent walking. Perceived neighborhood safety, on the other hand, was not significantly associated with walking time. Previous studies examining the relation between physical activity and perceived safety have produced mixed results (16, 30). Lastly, neighborhood poverty was positively associated with increased walking time, findings similar to those reported by Ross (31). The reasons are likely complex but may involve the relation of poverty to land-use mix in urban versus suburban neighborhoods, more reliance on nonautomobile transport in poor communities, and normative walking behaviors in poor neighborhoods.

Only 3.6 percent of the variability in reported walking time among our sample was attributable to differences between the municipally defined neighborhoods that served as the primary sampling units in this study. This finding is compelling in light of the significant associations found between walking and the built environment surrounding participants' residences. It suggests that the variability in built environment characteristics was greater within municipally defined neighborhoods than between them, indicating that local neighborhood is a more appropriate geographic scale for determining the effect of built environment on walking behavior. Currently, there is little agreement on the appropriate scale to best measure built environment in regard to its association with walking behavior, although there appears to be a trend toward utilizing objective measures within ''walkable'' buffer zones similar in scale to the ones used in this study (10, 28, 32). Additionally, some built environment characteristics, for example, accessibility of retail and services, were more important at the very local level (quarter-mile radius), while other built environment characteristics, for example, traffic volume, were more important in a larger geographic area (half-mile radius). This finding is consistent with the theory that the appropriate geographic scale differs by built environment characteristics, which further supports the usefulness of characterizing a local neighborhood by using geographic information systems in future studies.

Several limitations of the current study warrant discussion. First, the cluster-randomized design of the original SHAPE trial resulted in small within-neighborhood sample sizes. This limitation reduced our ability to accurately model the variability in walking activity associated with differences in municipally defined neighborhood residence.

Nevertheless, given the negligible intergroup variability in walking time calculated in the unconditional means model, we do not think that this variability resulted in misestimation of the associations between local built environment characteristics and walking activity. We do recognize that the necessity of adopting a two-stage modeling approach resulted in relatively small within-group sample sizes for the analyses of walking times, which were further reduced in the subanalyses of walking type. This reduction may have limited our ability to detect significant associations between specific types of walking and built environment characteristics. Second, the city of Portland has an established history of managing urban growth and promoting ''pedestrian-friendly'' urban planning initiatives, which may limit generalizability of the findings. Similarly, because many characteristics of a pedestrian-friendly built environment are highly correlated, it is difficult to differentiate the effects of individual characteristics.

Third, we lacked data on disease risk or prevalence among our sample; unmeasured confounding by poor health could result in inflated estimates of the association between built environment and walking. However, models were controlled for self-reported health, minimizing concerns about substantial residual confounding. Lastly, this study relied upon self-reported measures of physical activity, which may be subject to self-report or recall bias. Self-report measures continue to be the standard method of assessing physical activity in large studies such as this one, and the scope of this study made the use of objective measures, such as pedometers, impractical.

In summary, this study found that characteristics of the local built environment—street volume and proximity of walking destinations—were independently associated with increases in the level of walking activity among older adults who favor walking. However, we found that the odds of having walked for any length of time during a typical week in the past month were not associated with objective measures of the built environment. These findings suggest that promotion of mixed land-use and pedestrian-friendly neighborhood design could play a significant role in encouraging more vigorous activity among moderately active older adults, although such environmental interventions may have little effect on the behavior of highly sedentary older adults. For older adults who are not already active, approaches to reduce inactivity should focus on physical or psychological concerns, such as chronic medical conditions, declining physical function, history of (in)activity over the life course, and self-efficacy. Future research is needed to clarify the relation between built environment and walking activity among highly sedentary older adults, to confirm the appropriate geographic scale for measurement of neighborhood built environment in studies of older adults, and to examine the effects of environmental interventions on walking behavior over time.

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C. N. performed the literature review, codesigned the analytic approach, conducted data analysis, and prepared the manuscript for submission. N. C. codesigned the analytic approach, supervised data analysis, and assisted in preparation of the manuscript. M. B. provided geographic information system data and assisted in the design of appropriate variable selection and mapping techniques. Y. M. had overall responsibility for the design and implementation of the study, assisted in the interpretation of analysis results, and assisted in preparation of the manuscript.

Conflict of interest: none declared.

REFERENCES

1. Agency for Healthcare Research and Quality. Physical activity and older Americans: benefits and strategies. June 2002. (http://www.ahrq.gov/ppip/activity.htm).
2. DiPietro L. Physical activity in aging: changes in patterns and their relationship to health and function. J Gerontol A Biol Sci Med Sci 2001;56(spec no. 2):13–22.
3. Pate RR, Pratt M, Blair SN, et al. Physical activity and public health. A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. JAMA 1995;273:402–7.
4. Barnes PM, Schoenborn CA. Physical activity among adults: United States, 2000. Advance data from vital and health statistics; no. 333. Hyattsville, MD: National Center for Health Statistics, 2003. (http://www.cdc.gov/nchs/data/ad/ad333.pdf).
5. Eyler AA, Brownson RC, Bacak SJ, et al. The epidemiology of walking for physical activity in the United States. Med Sci Sports Exerc 2003;35:1529–36.
6. Siegel PZ, Brackbill RM, Heath GW. The epidemiology of walking for exercise: implications for promoting activity among sedentary groups. Am J Public Health 1996;85:706–10.
7. Hoehner CM, Brennan Ramirez LK, Elliott MB, et al. Perceived and objective environmental measures and physical activity among urban adults. Am J Prev Med 2005;28(suppl 2): 105–16.
8. King WC, Brach JS, Belle S, et al. The relationship between convenience of destinations and walking levels in older women. Am J Health Promot 2003;18:74–82.
9. Suminski RR, Poston WS, Petosa RL, et al. Features of the neighborhood environment and walking by U.S. adults. Am J Prev Med 2005;28(suppl):149–55.
10. Pikora TJ, Giles-Corti B, Knuiman MW, et al. Neighborhood environmental factors correlated with walking near home: using SPACES. Med Sci Sports Exerc 2006;38:708–14.
11. Saelens BE, Sallis JF, Black JB, et al. Neighborhood-based differences in physical activity: an environment scale evaluation. Am J Public Health 2003;93:1552–8.
12. Frank LD, Pivo G. Impacts of mixed use and density on utilization of three modes of travel: single-occupant vehicle, transit, and walking. Transport Res Rec 1994;14:44–52.

13. Berrigan D, Troiano RP. The association between urban form and physical activity in U. S. adults. Am J Prev Med 2002; 23(suppl):74–9.
14. Ball K, Bauman A, Leslie E, et al. Perceived environmental aesthetics and convenience and company are associated with walking for exercise among Australian adults. Prev Med 2001;33:434–40.
15. Giles-Corti B, Donovan RJ. Socioeconomic status differences in recreational physical activity levels and real and perceived access to a supportive physical environment. Prev Med 2002; 35:601–11.
16. Owen N, Humpel N, Leslie E, et al. Understanding environmental influences on walking: review and research agenda. Am J Prev Med 2004;27:67–76.
17. Cunningham GO, Michael YL. Concepts guiding the study of the impact of the built environment on physical activity for older adults: a review of the literature. Am J Health Promot 2004;18:435–43.
18. Li F, Fisher KJ, Brownson RC, et al. Multilevel modelling of built environment characteristics related to neighborhood walking activity in older adults. J Epidemiol Community Health 2005;59:558–64.
19. Fisher KJ, Pickering MA, Li F. Healthy aging through active leisure: design and methods of SHAPE—a randomized controlled trial of a neighborhood-based walking project. World Leisure J 2002;1:19–28.
20. Dipietro L, Caspersen CJ, Ostfeld AM, et al. A survey for assessing physical activity among older adults. Med Sci Sports Exerc 1993;25:628–42.
21. Harada ND, Chiu V, King AC, et al. An evaluation of three self-report physical activity instruments for older adults. Med Sci Sports Exerc 2001;33:962–70.
22. Schuler PB, Richardson MT, Ochoa P, et al. Accuracy and repeatability of the Yale physical activity survey in assessing physical activity of older adults. Percept Mot Skills 2001; 93:163–77.
23. Michael YL, Green MK, Farquhar SA. Neighborhood design and active aging. Health Place 2006;12:734–40.
24. McAuley E, Mihalko SL. Measuring exercise-related self-efficacy. In: Duda JL, ed. Advances in sport and exercise physiology measurement. Morgantown, WV: Fitness Information Technology, 1998:371–90.
25. Office of Neighborhood Involvement. Portland neighborhood demographic profiles from the 1996 American Community Survey data. June 15, 2006. (http://gis.co.multnomah.or.us/pmpb/toppage.cfm).
26. Sallis JF, Johnson MF, Calfas KJ, et al. Assessing perceived physical environmental variables that may influence physical activity. Res Q Exerc Sport 1997;68: 345–51.
27. Raudenbush SW, Bryk AS. Hierarchical linear models: applications and data analysis methods. Newbury Park, CA: Sage, 2002.
28. Frank LD, Schmid TL, Sallis JF, et al. Linking objectively measured physical activity with objectively measured urban form: findings from SMARTRAQ. Am J Prev Med 2005; 28(suppl):117–25.
29. Adult participation in recommended levels of physical activity—United States, 2001 and 2003. MMWR Morb Mortal Wkly Rep 2005;54:1208–12.
30. Humpel N, Owen N, Leslie E. Environmental factors associated with adults' participation in physical activity: a review. Am J Prev Med 2002;22:188–99.
31. Ross CE. Walking, exercising, and smoking: does neighborhood matter? Soc Sci Med 2000;51:265–74.
32. Wendel-Vos GC, Schuit AJ, de Niet R, et al. Factors of the physical environment associated with walking and bicycling. Med Sci Sports Exerc 2004;6:725–30.